# UNRESTRICTED RELEASE MEASUREMENTS WITH AMBIENT AIR IONIZATION MONITORS

Duncan MacArthur, Los Alamos National Laboratory
Richard Gunn, Thomas Dockray, Craig Luff, BNFL Instruments (UK)

## ABSTRACT

Radiation monitoring systems based on the long-range alpha detection (LRAD) technique, such as the BNFL Instruments IonSens™, provide a single contamination measurement for an entire object rather than the more familiar series of individual readings for smaller surface areas. The LRAD technique relies on the ionization of ambient air molecules by alpha particles, and the subsequent detection of these ions, rather than direct detection of the alpha particles themselves. A single monitor can detect all of the ions produced over a large object (pipe, I-beam, reinforcing bar, etc.) and report a total contamination level for the entire surface of that object. Currently, both the unrestricted release limits specified in USDOE Order 5400.5 (and similar documents in other countries), and the definitions of radioactive waste categories, are stated in terms of contamination per area (e.g. 20 dpm/100 $cm^2$). Thus, conversion is required between the total effective contamination as measured by the LRAD-based detector and the allowable release limits. This paper illustrates that the method chosen to average the assumed contamination over the object can have a significant impact on the effective sensitivity of the detector. In light of this, it may be reasonable to consider rewriting the release regulations to take advantage of the capabilities of averaging monitoring systems.

## INTRODUCTION

Currently, the release limits specified in USDOE Order 5400.5 (and similar documents in other countries) are stated in terms of contamination per area. Typically, contamination is to be measured over a relatively small area such as 100 $cm^2$ or 300 $cm^2$. This type of specification is well matched to the traditional hand-held monitoring instruments. However, hand-held instruments are limited in sensitivity, reliability, and in their ability to measure contamination on large or complex surfaces. In contrast, **averaging** radiation monitoring systems provide a single, sensitive, contamination measurement for the entire surface of an object rather than the more familiar individual readings for smaller surface areas. One example is the BNFL Instruments IonSens™, which is based on the long-range alpha detection (LRAD) concept. (1, 2) However, averaging instruments require interpretation of the regulations since these regulations were not written with averaging in mind.

The averaging assumptions used can significantly impact the one's ability to release an object. A much higher total contamination level (as measured with an averaging detector) is acceptable if the object can be assumed to be uniformly contaminated. If all of the contamination must be assumed to be in a single 100-$cm^2$ area, the gain due to the averaging technology is minimized. Note, however, that the other characteristics of LRAD monitors, such as the ability to monitor the inner surfaces of pipes as in the BNFL

Instruments IonSens™, may argue for the use of this type of detector even if no averaging is preformed.

If minimizing the total release of radioactive material is a good measure of the effectiveness of a release monitor, then averaging systems are more effective for unrestricted release monitoring than traditional monitoring systems that measure contamination over a small area. However, current release limit regulations were written with traditional instruments in mind. Thus, even if total contamination is arguably a better ‘yardstick’ for unrestricted release, these measurements must be converted to ‘per area’ values to allow release under current regulations.

**TECHNIQUE**

As illustrated in Fig. 1, the LRAD technique relies on the ionization of ambient air molecules by alpha particles. (3, 4) These ions are transported to an ion collector where the small current produced by this ion flow is measured with a sensitive electrometer. This current is proportional to the number of ions and hence to the strength of the contamination **averaged over the entire surface** from which air is collected.

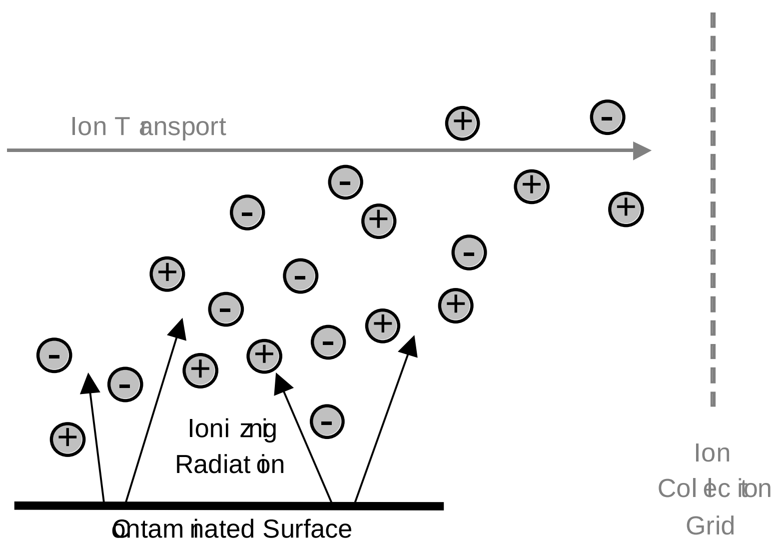


Fig. 1. The LRAD alpha particle detection technique. Alpha particles from a contaminated surface ionize ambient air molecules. These ions are transported to an ion collection grid where the number of ions can be measured as a small current. This current is proportional to the amount of contamination on **the entire surface** being monitored.

Thus, LRAD-based monitors do not depend on direct detection of the alpha particles themselves. The LRAD-based monitoring systems are limited by the distance than the ions can travel through the air (several meters) rather than the range of the alpha particle (several centimeters). A single monitor can detect all of the ions produced over a large object (pipe, I-beam, reinforcing bar, etc.) and report a total contamination level for that object. ( 5)

## AVERAGING MEASUREMENTS

The output of the LRAD ion detector (I) in response to a number of alpha decays within the detector ($N_A$) is given by

$$I = GF\varepsilon_I\varepsilon_A N_A, \qquad \text{(Eq. 1)}$$

where G is the electronic gain of the detector and F is the fraction of the ions generated within the active volume that are transported to the ion detector. In this case, $\varepsilon_I$ is the efficiency of conversion of alpha particles in free air into ions and $\varepsilon_A$ is the fraction of alpha energy that is deposited into the air of the detector (as opposed to nearby solid material).

The electronic gain, G, is known and controllable, and the ion conversion efficiency, $\varepsilon_I$, can be calculated directly from the properties of the detection gas and the incident alpha particle. (An alpha particle loses about 35 eV per ion pair generated in air, so a typical 5-MeV particle will generate about 140,000 ion pairs.) The factors F and $\varepsilon_A$ depend on the details of the object/detector system; understanding these geometry factors is essential for relating the contamination measured by the LRAD-based detector to the surface release limits.

Several limiting cases may help to illustrate the interactions between these parameters:

1. If the radiation is generated within a plated calibration source, then almost 1/2 of the alpha particles are emitted into the air above the source; i.e. $\varepsilon_A \approx 1/2$.
2. If the ion detector is very close to a small alpha source, then almost all of the ions can be collected; i.e. $F \approx 1$.
3. If the alpha contamination is located in a thick deposit or not located with 2- to 3-cm of air in all directions, then $\varepsilon_A$ is not as easy to calculate. In most cases (excluding airborne contamination) the efficiency can be bounded, $0 < \varepsilon_A < 1/2$. However, in general, this bounding is of little practical use.
4. If the alpha contamination is located in a complex geometry or the ion detector is located far from the contamination, then F are not as easy to calculate.

To summarize, $\varepsilon_A$ is a measure to the number of ions generated in the surrounding air by each alpha decay. The parameter F is related to the effectiveness of the transport system in transporting these ions between the contaminated area and the ion detector. F is determined by the detection system and is not variable once the detector has been defined. However, $\varepsilon_A$ is determined by the type of measurement and measurement assumptions being made. It is instructive to consider two cases, the spot measurement where are contamination is assumed to be contained within a single 100-$cm^2$ area, and the surface measurement, where the contamination is assumed to be uniformly spread over a larger surface area.

SPOT MEASUREMENTS

If all of the contamination on an object is (or must be assumed to be) in a single spot, then the outputs from an averaging detector and a traditional detector should be identical. In this case, a "spot" is defined as an area smaller than the regulatory specification (100 $cm^2$, 300 $cm^2$, etc.) If the amount of radioactivity that is measured by the averaging detector is X dpm, then the measured value for comparison with release limits would be X dpm/100$cm^2$ and the LoD of the measurement system would be given by

$$\text{LoD}_{\text{measurement}}\ (\text{dpm}/100\ \text{cm2}) = \text{LoD}_{\text{detector}}\ (\text{dpm}) \qquad \text{(Eq. 2)}$$

Taking a more concrete example, the Limit of Detection (LoD) specification for the BNFL Instruments IonSens™ is 15 Bq (900 dpm) for 6σ confidence in 300 s. Converting this to the more commonly used 95% confidence level, the LoD becomes

$$LoD(95\%) = LoD(6\sigma) \times \frac{2\sqrt{2}}{6} \qquad \text{(Eq. 3)}$$

Thus, the LoD(95%) is approximately 7.5 Bq (450 dpm) in 300 s. The detector response is totally dominated by statistical noise near this LoD, so the relationship between LoD and measurement time (MT) is given by

$$LoD \propto \frac{1}{\sqrt{MT}}, \qquad \text{(Eq. 4)}$$

or, in this case

$$LoD = \frac{450}{\sqrt{MT/300}}\ \text{dpm}\ . \qquad \text{(Eq. 5)}$$

For reference, Eq. 5 is displayed graphically in Fig. 2. This figure displays the sensitivity of the IonSens™ monitor as a function of measurement time.

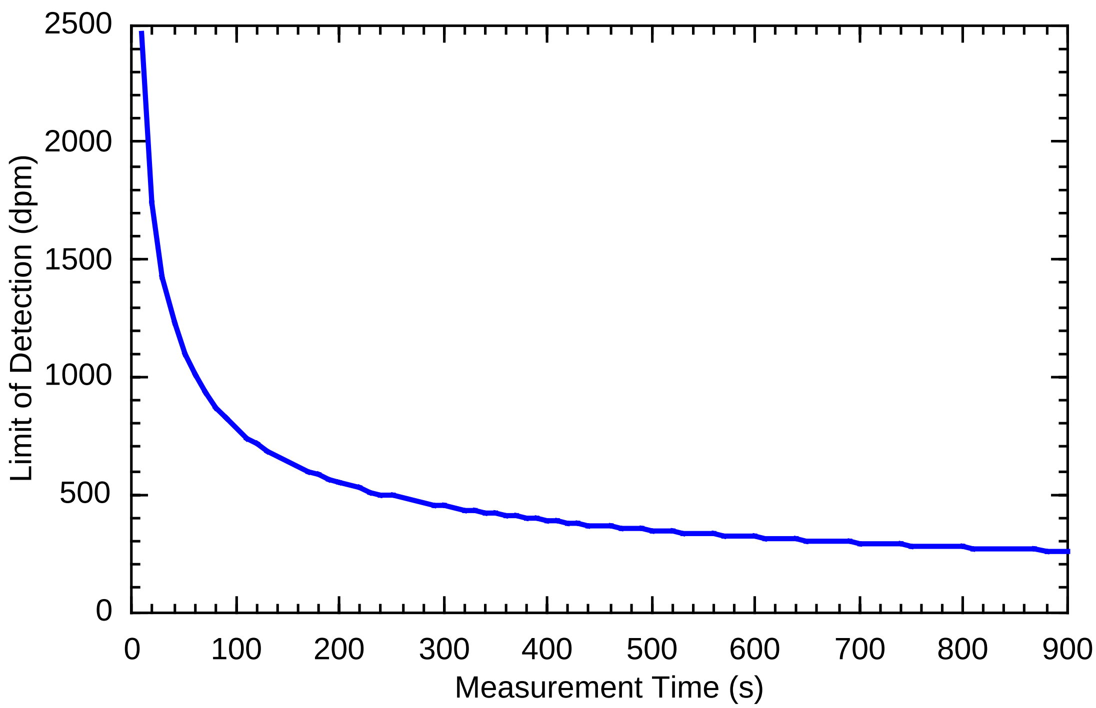


Fig. 2. Limit of Detection (LoD) of the stock IonSens monitor for localized contamination as a function of measurement time. This assumes that the LoD of the IonSens in 300 s is specified as 450 dpm.

## SURFACE MEASUREMENTS

If the contamination is spread evenly over the entire surface of an object, then the effective sensitivity is much better for a given LoD. If the total amount of radioactivity that is measured by the averaging detector in this case is again X dpm, and the surface area of the object being measured is Y $cm^2$, then the measured value for comparison with release limits would now be X (100/Y) dpm/100$cm^2$ and the LoD for the measurement becomes

$$LoD_{measurement}\ (dpm/100\ cm2) = (100/Y)\ LoD_{detector}\ (dpm) \qquad \text{(Eq. 6)}$$

Thus the effective LoD of the measurement has been reduced by a factor of Y/100.

Again, a concrete example may clarify matters. If the surface area of a section of pipe is 3,000$cm^2$ and the release limit is 20 dpm/100 $cm^2$ **averaged** over the entire pipe, then the total limit as measured in a averaging detector is 600 dpm. Thus, the IonSens should be able to make this measurement in somewhat less than 300 s.

The inner area (Y) of a pipe that is L-cm long and D-cm in diameter is given by

$$Y = \pi LD. \qquad \text{(Eq. 7)}$$

Thus, for a pipe with a uniformly contaminated interior, the measured LoD is given by

$$LoD_{measurement}\ (\text{dpm/100 cm2}) = (100/\pi LD)\ LoD_{detector}\ (\text{dpm}). \qquad \text{(Eq. 8)}$$

The standard IonSens system can incorporate 1, 2, or 3 chamber modules; each 2-m in length. The IonSens is also specified to measure pipes from 5-cm to 15-cm in diameter. Figure 3 is a graph of the averaged detection limit (Eq. 8) for three lengths of pipes in the specified diameter range.

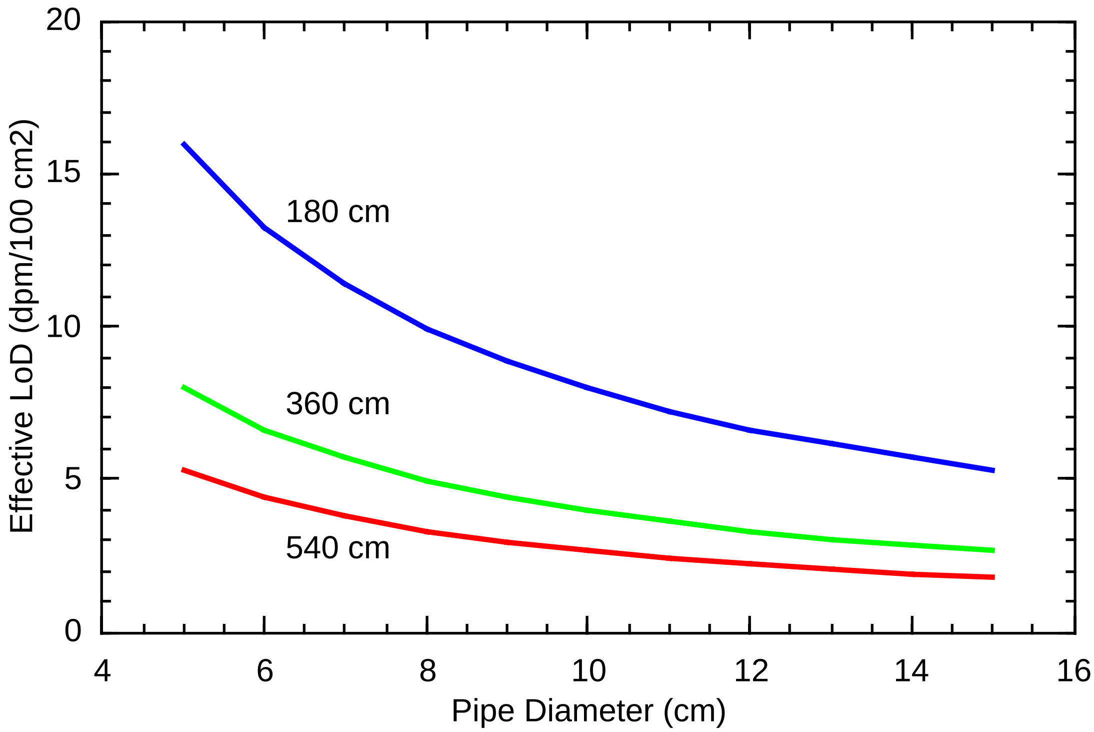


Fig. 3. Effective LoD as a function of pipe diameter for "typical" pipe lengths of 180 cm (6 ft), 360 cm (12 ft), and 540 cm (18-ft) in an IonSens pipe monitor. This graph assumes that contamination is uniformly spread over the interior of the pipe and that the specified LoD for the IonSens is 450 dpm. The measurement time is 300-s.

The effective LoD as shown in Fig. 3 is very low for a measurement time of 300-s. If the contamination is averaged over a large pipe surface, a shorter measurement time may be appropriate. Figure 4 illustrated the effective LoD under the same conditions as Fig. 3, but using a measurement time of 100-s. This figure results from applying both Eq. 4 and Eq. 8 to the basic LoD of 450 dpm in 300 s.

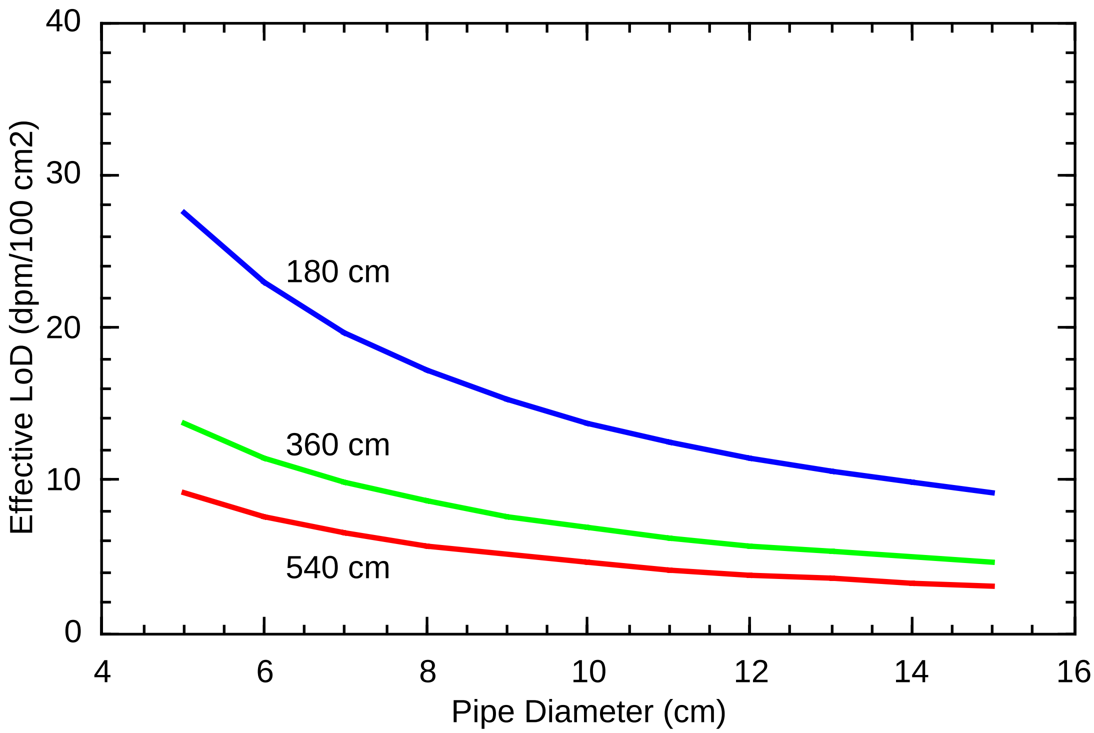


Fig. 4. Effective LoD as a function of pipe diameter for “typical” pipe lengths of 180 cm (6 ft), 360 cm (12 ft), and 540 cm (18-ft) in an IonSens pipe monitor. This graph assumes that contamination is uniformly spread over the interior of the pipe and that the specified LoD for the IonSens is 450 dpm. The measurement time is 100-s.

RETURN ON INVESTMENT

A system such as the IonSens returns the initial cost of the system in two ways – **labor savings** for production surveys of items and **avoidance of disposal costs** for items with inaccessible contamination, which otherwise would require disposal as LLW. Preliminary data on the performance of the IonSens™ is presented below. (6)

The rate at which pipe can be surveyed by the IonSens monitoring system is determined by the level of sensitivity required. The typical measurement time required to achieve a 95% confidence level is one minute. The “support” time (loading, unloading and data recording) required for each measurement is approximately three minutes. Comparing this rate of production with that of traditional hand surveys, the IonSens™ can produce monitored pipe at a rate that is a factor of ten higher than manual methods.

Table I illustrates a direct comparison of survey rates for the IonSens™ versus the rate achieved using the manual probe method. For the manual method, the probe is only effective over a width of approximately 2.5-cm due to the curvature of the pipe. Also, traditional survey methods could only be used on the exterior and ends of the pipes. The IonSens™ not only surveys both inside and outside surfaces in a single measurement, but also performs the survey on surfaces that are inaccessible to the manual probe.

Table I. Production Survey Rates for Manual Methods versus IonSens™. For these measurements, the pipes were 5-cm in diameter pipe and 180-cm long; thus, the total surface area of each pipe (both sides) was about 5600-cm$^2$.

| IonSens™ | | Hand-Held Probe | |
|---|---|---|---|
| Measurement Time -Electrical (s) | 60 | Scan Speed (cm/s) | 1.0 |
| Measurement Time – Total (s) | 240 | Scan Width (cm) | 2.54 |
| | | | |
| Monitoring Rate (cm$^2$/hr) | 84,000 | Monitoring Rate (cm$^2$/hr) | 9,100 |
| Relative Labor Cost | $0.11 | Relative Labor Cost | $1.00 |

As shown in Table I, the labor cost for IonSens™ Monitoring is typically about 11 percent of the labor cost associated with traditional monitoring. Given this ratio, a typical customer, monitoring pipes in 180-cm (6-ft) lengths, would pay back the capital cost of the monitoring system in approximately 500 hours of operation.

The cost of disposal can be reduced by survey and release of the pipes that would otherwise require disposal as LLW, due to the inaccessible surfaces inside the pipe. Based on an assumed disposal cost of $40 per cubic foot, the payback period for disposal cost avoidance would be a reduction of 4375 cubic feet. A single IonSens™ monitor can survey this volume of pipe in approximately 1700 hours.

## CONCLUSIONS

Average measurement systems, such as the IonSens pipe monitor, can be used extremely effectively in situations where the contamination can be assumed to be uniformly distributed over an entire object. In particular, the 20 dpm/100 cm$^2$ release limit for removable plutonium can be effectively monitored on reasonable sized pipes.

This measurement system can still be used effectively if the contamination must be assumed to be in one spot. However, in this case, plutonium contamination would have to be fixed so that a larger limit, such as the 500 dpm/100cm$^2$ limit specified by USDOE 5400.5, would apply. This could be achieved by cleaning the pipe to remove loose contamination prior to monitoring. Either fixed or removable uranium could be effectively measured with the IonSens.

Systems such as the IonSens™ can be used as an effective part of an operating cost reduction program for health physics departments and waste minimization programs. The initial investment in an IonSens™ pipe monitoring system can be repaid in less than one year of operation on pipe and similar objects.

## REFERENCES


1. D. W. MacArthur, M. Rawool-Sullivan, and T. Dockray, "Detection of Alpha Contamination Inside Pipes," Proceedings of WM'96, Tucson AZ, February 25-29, 1996.

2. http://www.bnflinst.co.uk/

3. D. W. MacArthur, K. S. Allander, J. A. Bounds, M. M. Catlett, R. W. Caress, and D. A. Rutherford, "Alpha Contamination Monitoring of Surfaces, Objects, and Enclosed Areas," IEEE Transactions on Nuclear Science, Volume 40, Number 4, Page 840 (1993).

4. D. W. MacArthur, K. S. Allander, J. A. Bounds, and J. L. McAtee, "LRAD-Based Contamination Monitoring of Personnel and Equipment," Nuclear Technology v. 102, p. 270 (1993).

5. Mohini W. Rawool-Sullivan, J. G. Conaway, D. W. MacArthur, and J. Vaccarella, "Alpha Contamination Assessment for D&D Activities: Monitoring Pipe Interiors," Los Alamos National Laboratory Publication LA-13064-MS, 1995.

6. This data was taken for recent demonstration (12/98 through 1/99) as part of the Large Scale Demonstration Project at the USDOE Savannah River Site, funded by the Office of Technology Deployment of EM-50.